Event Shapes in $t\bar{t}$ and QCD Events at the LHC

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Outline

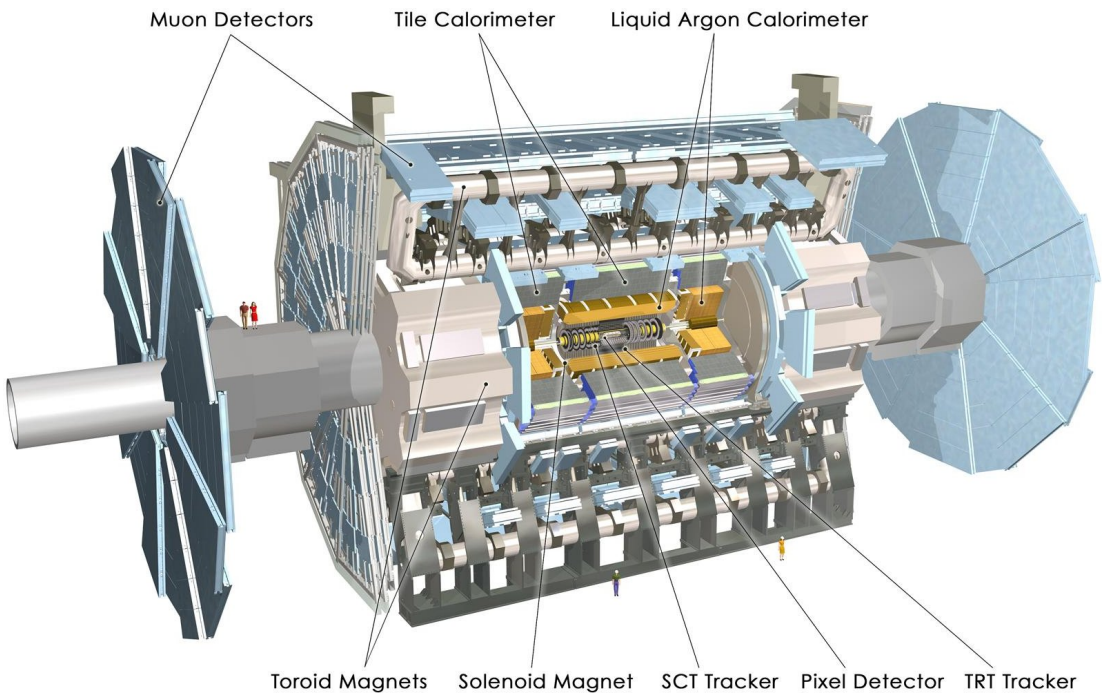
The ATLAS Experiment at the LHC

- The LHC will create $p - p$ collisions at energies of $\sqrt{s} = 14\,\text{TeV}$
- 2009: Collisions at $\sqrt{s} = 900\,\text{GeV}$ and $2.36\,\text{TeV}$

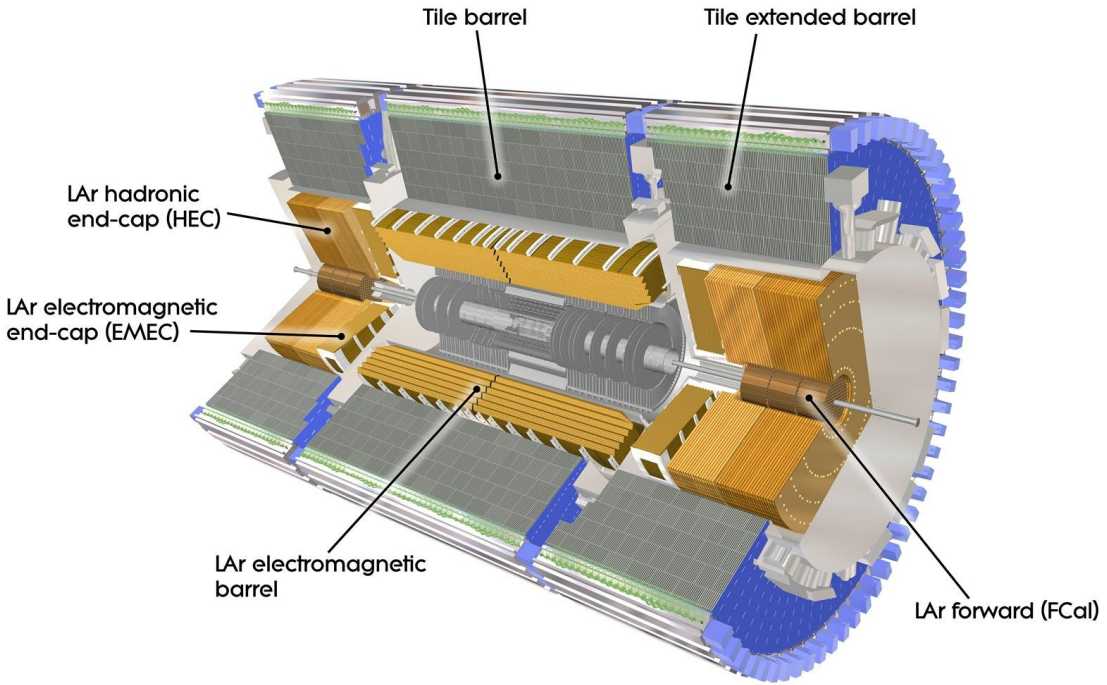
- 2010: Collisions at $\sqrt{s} = 7\,\text{TeV}$ anticipated, $\mathcal{L} \approx 100\,\text{pb}^{-1}$
- Will be a top quark factory ($\mathcal{O}(10\text{k})$ top quark pairs)
- Four major physics experiments: ALICE, ATLAS, CMS, LHCb
- ATLAS: A Toroidal LHC ApparatuS – One of two multi-purpose experiments at the LHC

The ATLAS Experiment at the LHC

- Main aims of the ATLAS experiment:
  - Find or exclude the Higgs boson
  - Find evidence for Supersymmetry and Dark Matter
  - Search for extra dimensions
  - Investigate CP violation and QCD processes



The ATLAS Calorimeter System



- Total coverage: $|\eta| \leq 4.9$ $(\theta \leq 0.85°)$
- A total of $192\,000$ readout channels

- High granularity up to $|\eta| \leq 2.5\,(\theta \leq 9.4°)$
- Allows for reconstruction of single final state particles, perfect for calculating Event Shapes

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

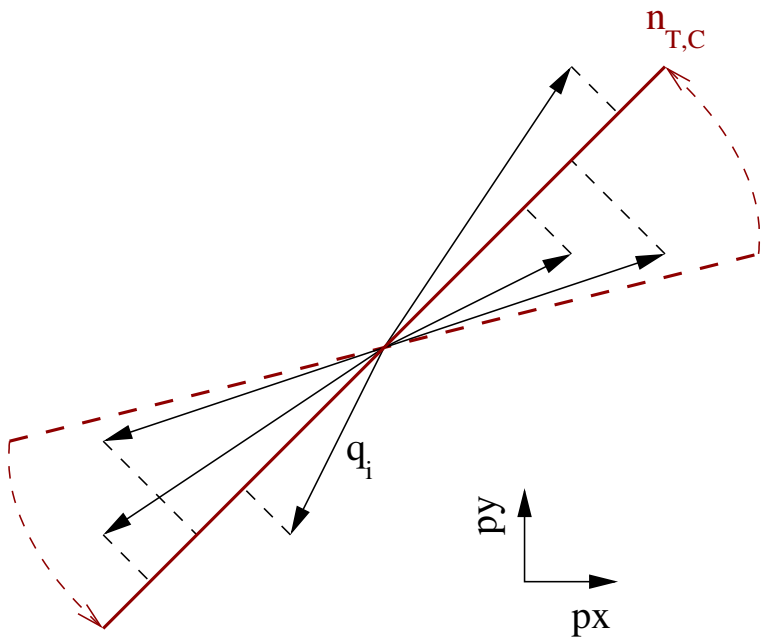
Calculating Event Shapes

- One of the best known Event Shapes: Transverse Thrust
- Project calorimeter clusters on Thrust axis $n_{T,\mathcal{C}}$

Transverse Thrust definition

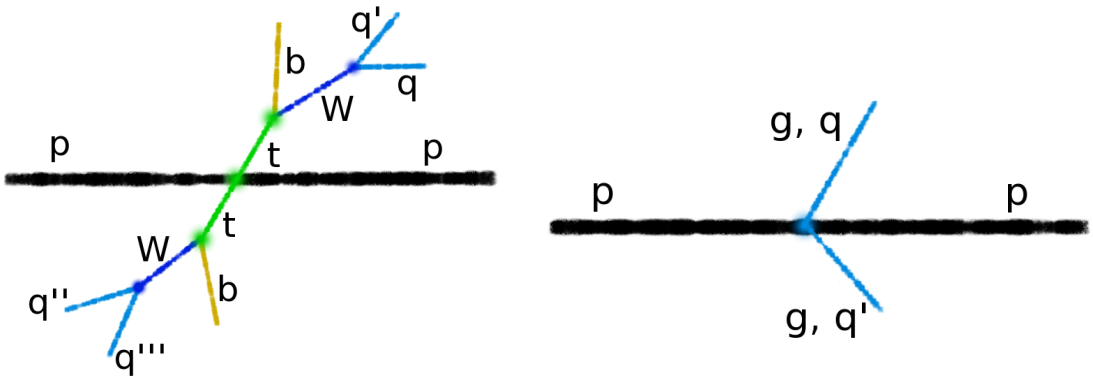
$$T_{\perp,\mathcal{C}} = \max_{\vec{n}_{T,\mathcal{C}}} \frac{\sum_{i\in\mathcal{C}} |\vec{q}_{\perp i} \cdot \vec{n}_{T,\mathcal{C}}|}{\sum_{i\in\mathcal{C}} |\vec{q}_{\perp i}|}$$

$\mathcal{C}$: Central region up to $|\eta| = 2.5$



- Require leading jets to be within central region
- Normalization to sum of all transverse momenta
- For two collimated jets $T_{\perp,\mathcal{C}} \rightarrow 1$,
  for isotropic events, $T_{\perp,\mathcal{C}} \rightarrow \frac{1}{2}$

Why Event Shapes?



- Event Shapes are theoretically well understood and experimentally accessible
- Important for QCD and tuning Monte Carlo generators
- Jets with higher invariant masses have a greater opening angle, hence a smaller Thrust value

Event Shapes in $t\bar{t}$

Event Shapes are sensitive to invariant masses,
hence reflect if a top quark is in the event

Event Shapes in Signal and Background

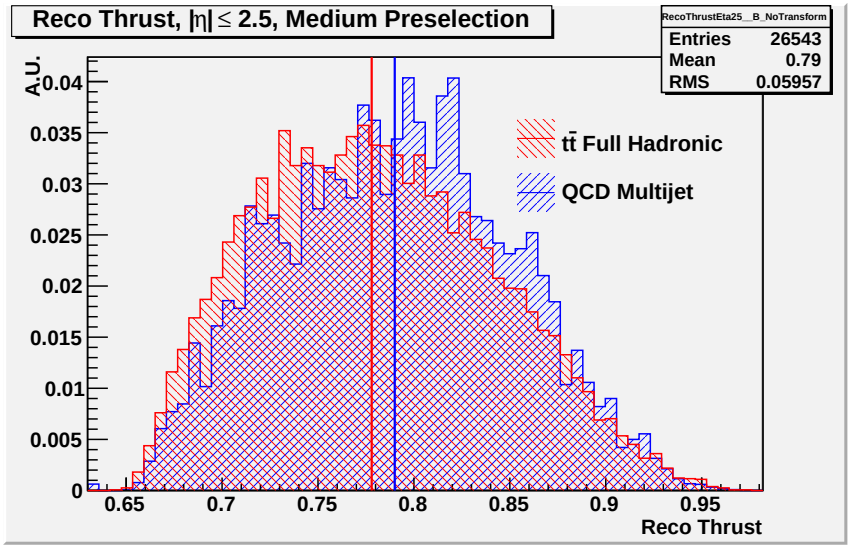


Figure: Transverse Thrust

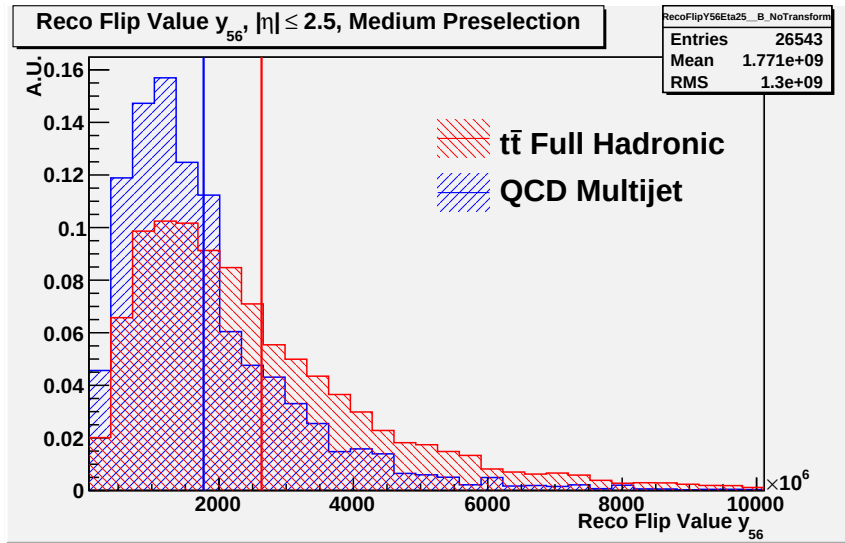


Figure: Flip Value y_{56}

- Works well for Thrust
- Works even better for other Event Shapes

From Thrust to Multivariate Analysis

- In principle, we can now use Event Shapes in an analysis to discriminate signal and background
- Problem: One Event Shape variable does not have enough discrimination power to discriminate signal from background

Multivariate Analysis

Solution: Combine multiple Event Shape variables

- Multiple approaches possible: Neural Networks, BDT, Likelihood Analysis or Fisher Discriminant
- Fisher method found to work best in the analysis, uses linear combination of input variables

Results

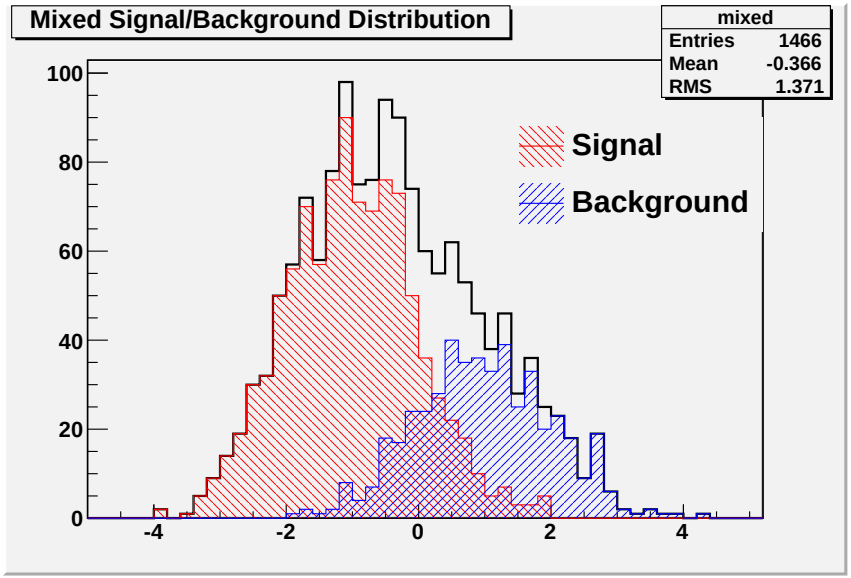
- Signal: $t\bar{t}$ full hadronic (MC@NLO, $\sqrt{s} = 10\,\text{TeV}$)
- Background: QCD multijet events (Pythia, $\sqrt{s} = 10\,\text{TeV}$)
- Preselection: 6 Jets, $2 \times 40, 4 \times 20\,\text{GeV/c}$
- Tag Jets: Require two leading jets to be within $|\eta| \leq 2.1$
- Application of the Fisher method
- Cut flow for $100\,\text{pb}^{-1}$:

	Before cuts	Preselection	Tag Jets	Fisher
Signal	15000	8800	910	360
Background	$3.2 \cdot 10^8$	$5.0 \cdot 10^6$	$1.4 \cdot 10^5$	$1.4 \cdot 10^4$
S/B	$4.7 \cdot 10^{-5}$	$1.8 \cdot 10^{-3}$	$6.5 \cdot 10^{-3}$	$2.6 \cdot 10^{-2}$

Result

S/B gain by a factor of 14 between Preselection and Fisher

Measuring Event Shapes (Work in Progress)



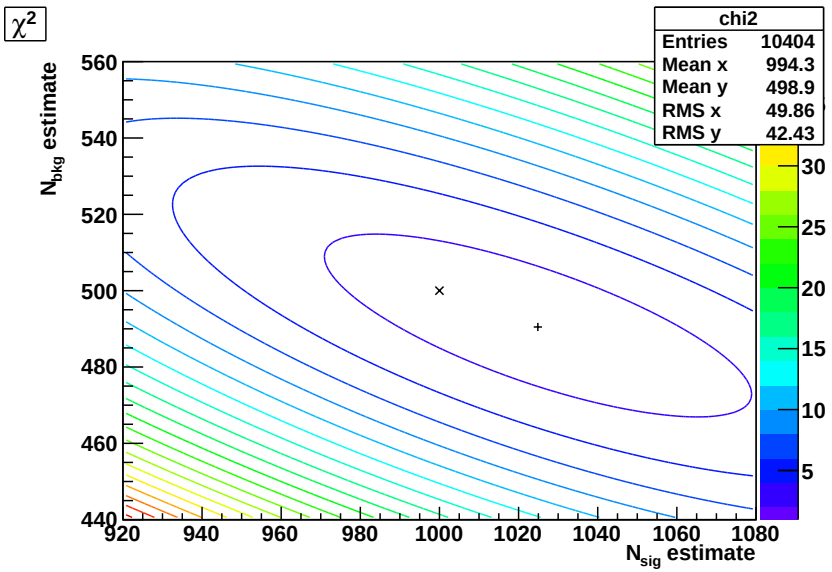
- We want to measure the signal and background rate, using a cut based "matrix method"
- Example with a toy model (two gaussian distributions)

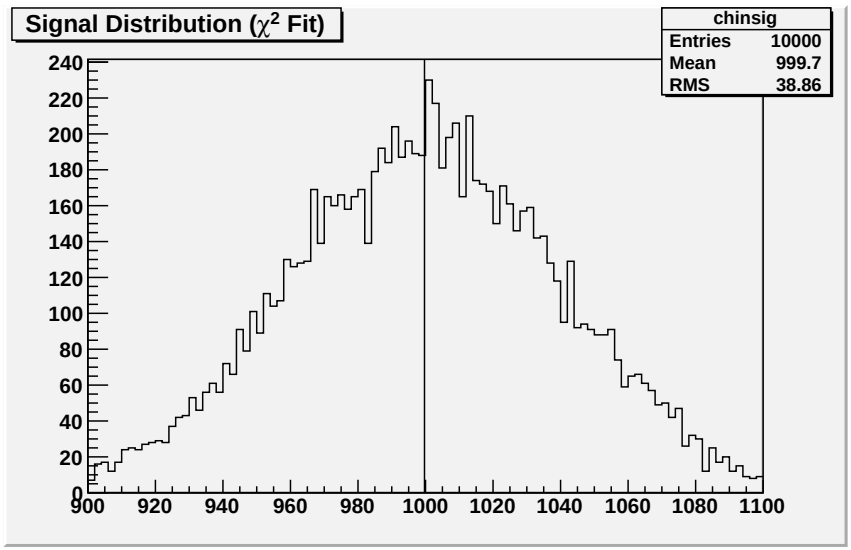
- For a certain cut value, the number of observed events is:

$$N_{\text{obs}}^{(\text{cut } 1)} = \varepsilon_{\text{sig}}^{(1)} \cdot N_{\text{sig}} + \varepsilon_{\text{bkg}}^{(1)} \cdot N_{\text{bkg}}$$
$$N_{\text{obs}}^{(\text{cut } 2)} = \varepsilon_{\text{sig}}^{(2)} \cdot N_{\text{sig}} + \varepsilon_{\text{bkg}}^{(2)} \cdot N_{\text{bkg}}$$

- The efficiencies ε are taken from simulation
- Can solve for N_{sig} and N_{bkg} using two cuts, least squares fit for more than two cuts

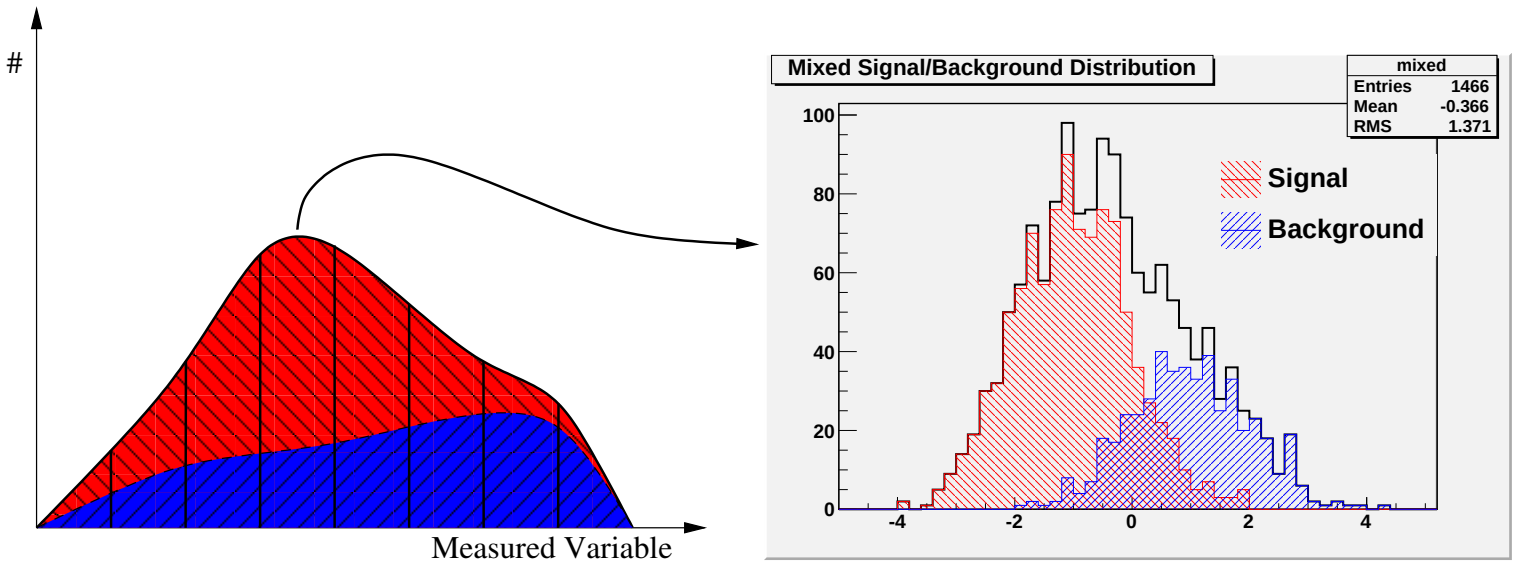
Measuring Event Shapes (Work in Progress)





- Left: Fit of N_{sig} and N_{bkg} in a five cut scenario. Isolines at $\Delta\chi^2 = 2$
- Right: Distribution of reconstructed N_{sig} from an ensemble test with 10000 entries. Shows that σ is of order $\sqrt{N}$

Measuring Event Shapes (Work in Progress)



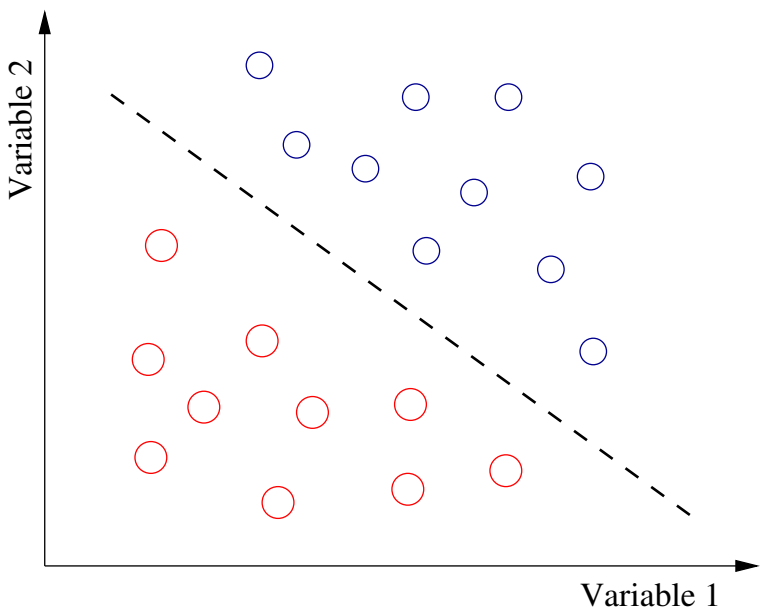
- Next step: Measure a shape distribution at five different cuts
- Assumption: Distribution across 1 bin is accurate
  Efficiencies obtained with Monte Carlo simulations are right
- Then: Perform the least squares fit in each bin,
  obtain the signal distribution for the whole histogram
- Still has to be fully implemented and tested on
  different generators

Summary

- Event Shapes are a valuable tool for discriminating top quark events
- Also valuable for measuring QCD properties and tuning Monte Carlo generators
- May be used for measuring the top quark mass
- Event Shapes used in a multivariate analysis were found to improve the S/B ratio by a factor of 14
- I am currently working on a method to measure signal and background distributions of Event Shapes

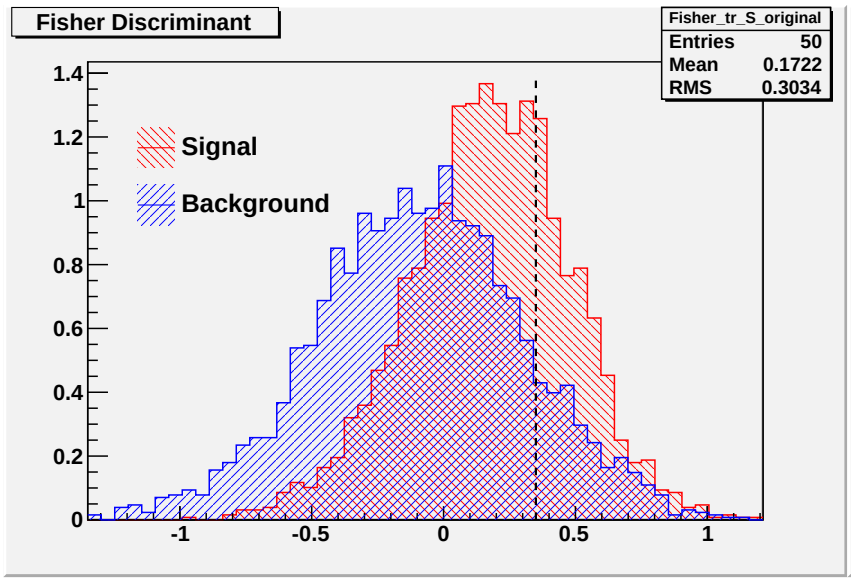
Fisher Discriminant

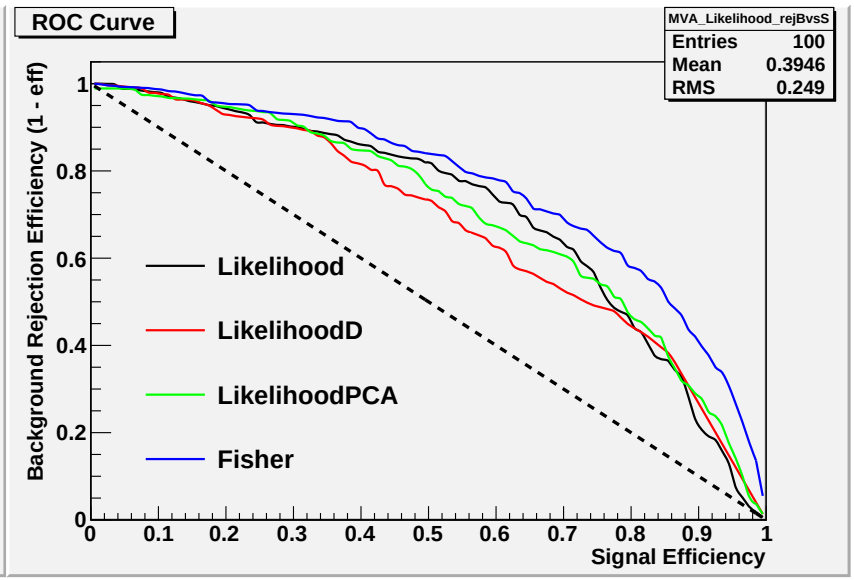
- Mathematically, transforms the variable space
- A linear combination of all input variables
- Determines a hyper plane which separates the signal and background as far as possible



- Works best on uncorrelated gaussian distributions with different mean values

Results





- Fisher performs better than Likelihood and other analyses

Pull Distribution